Modeling Your Water Balance

Purpose

Use GLOBE temperature, latitude, and precipitation data to model the change in soil water storage over a year's time, then to compare your model with GLOBE soil water content and biometry data.

Overview

Students will create a physical model using glasses to represent the soil column that illustrates the soil water balance. They will use data from the GLOBE Data Server to calculate the potential evapotranspiration (the amount of water needed to meet the demand for the month), average monthly temperatures and precipitation for their model. They will then construct a model representing the soil water balance for their site.

Time

One class period to calculate values

One class period to construct model

One class period for hypothesis testing

Level

Intermediate and advanced

Key Concepts

Soil stores water.

Soil has a water holding capacity (field capacity).

Higher temperatures and longer periods of daylight increase evapotranspiration.

Precipitation is not equal to the amount of water stored in the soil.

Soil water content is related to vegetative growth.

Skills

Measuring volume and length
Following directions
Building models
Retrieving data from the GLOBE server
Reading graphs
Calculating averages
Testing hypotheses using models
Graphing GLOBE data

Materials and Tools

14 beakers, glasses, or graduated cylinders (approximately 20-25 cm tall, or tall enough to hold the total precipitation for the wettest month at your model site)

Water (or other medium to represent precipitation such as rice)

Red and black markers

Ruler

Data from example or from GLOBE server

Preparation

For advanced activity: Collect GLOBE temperature, precipitation, GPS, soil moisture, biomass and hydrology data

Prerequisites

Simple math calculations, reading graphs, using GLOBE Data Server

Background

The amount of water stored in the soil at your site can be estimated by conducting a water balance for your area. The water content of your soil varies depending on the balance between water gained due to precipitation and water lost through evaporation and transpiration. The combined amounts of water lost through evaporation and transpiration is called evapotranspiration. The maximum rate of evapotranspiration would occur if water was always available and is called potential evapotranspiration. The water content of your soil is a key factor in determining which plants can grow in your area. Several factors control the water content of your soil including temperature, the duration of sunshine, the amount of groundcover and the amount of precipitation. One might think that the months of highest precipitation would also be the months with the greatest soil water content. This may be true- but maybe not - if the temperatures are so great that most of the water evaporates! Scientists study the water balance in an area to predict when plants will grow and when they will be under stress due to lack of water.

Preparation

Discuss with students the importance of water held in the soil with your student. You may want to do the *Just Passing Through* activity to illustrate the holding capacity of different soils.

Copy the Work Sheets for students to use.

What to Do and How to Do It

Examine the data in Figure HYD-L-16.

Precipitation = total amount of precipitation for the month

Water Needed (PE) = Potential Evapotranspiration is the total amount of water that would be lost through evaporation and transpiration if water was always available.

Extra Water = Precipitation in excess of what is needed

Extra Water Needed = Water needed from storage to make up a shortage in precipitation

Water in Storage = Water stored in soil available for plants (cannot exceed 100 mm, because this is the field capacity for this site)

Water Shortage = Water that is needed in excess of precipitation and ground storage

Runoff = Water which is lost through runoff when precipitation is greater than need and ground storage is at capacity

Temperature = average monthly temperature

Figure HYD-L-16: Water Balance Table, Mt. Lemmon, AZ Practice Data

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Precipitation (mm)	69	23	98	56	9	23	183	71	23	32	68	54	
Water Needed (PE in mm)	13	7	16	33	64	99	101	96	86	60	27	7	
Extra Water													
Extra Water Needed													
Water in Storage													
Water Shortage													
Runoff													
Temperature (avg in Celsius)	2	2	4	8	12	17	18	17	16	12	7	3	

1. Which month has the most precipitation? Which has the least?
2. Which month is the warmest? Which is the coldest?
3. During which months will water needed (PE) exceed precipitation?
4. During which months might you expect to have runoff?
5. Make a hypothesis on which month or months you would expect to have a water shortage. Record your hypothesis and your justification for your hypothesis in you GLOBE Science Notebook.

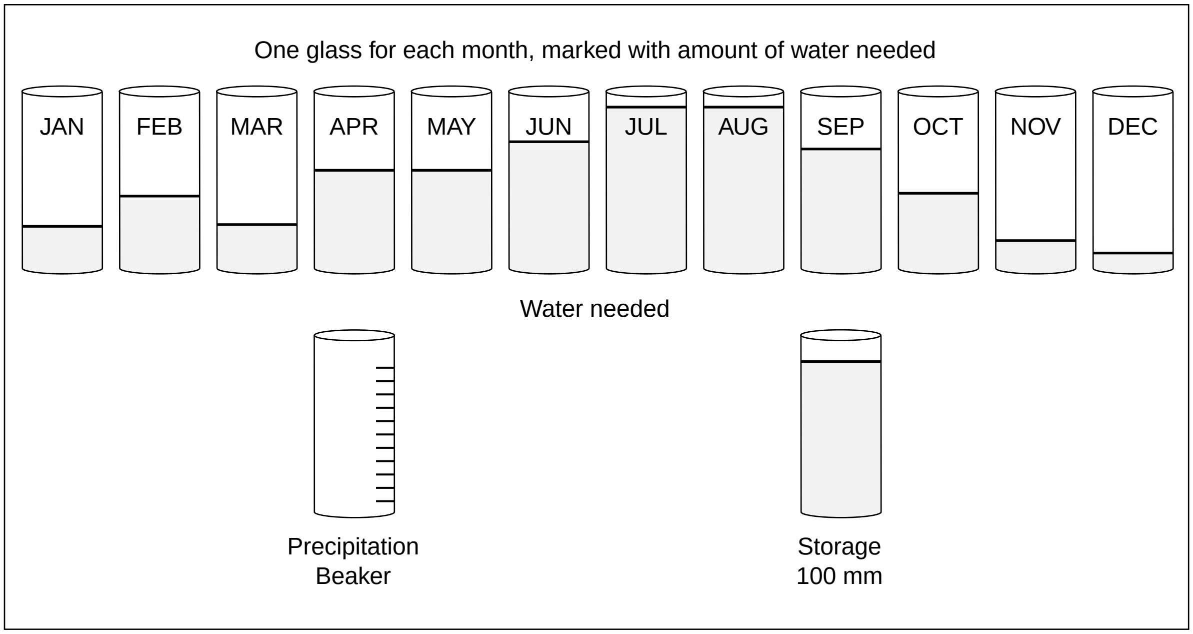
Setting Up Your Model

1. Set out 12 containers representing months of the year. Label them from January through December. See Figure HYD-L-17.
2. Find, in the table, the amount of potential evapotranspiration (PE) that is needed for each month. Draw a line on each container with a marker showing the mm of PE needed for that month.
3. Mark the 13th container as storage. Make a line at 100 mm on the container to indicate when storage is full.

Using Your Model

1. Begin modeling your water balance by measuring in the precipitation beaker the amount of precipitation you received for January. Then follow the procedure below:
   - If you have more precipitation than you need for the month, fill the month container only up to the PE line, then put the extra water from the precipitation beaker into storage.
   - The Storage container can only be filled to the 100 mm level; extra water is runoff and can be thrown away.
   - If you do not have enough precipitation for the month to fill to the PE line, pour all of the precipitation into the month container, then take water from storage and pour it into the month container until you reach the PE line.
   - If you still do not have enough water after pouring in all of the precipitation from the beaker and using all of the storage, make a red line on the glass at the water level to show a water shortage.
2. As you create the water balance model, fill in the Water Balance Table Work Sheet with the appropriate data for each month. (Review the example of the filled in Water Balance Table on the Water Balance Table Work Sheet.)

Figure HYD-L-17: Setting Up for the Water Balance Model



3. Repeat these steps for all of the months. Do the months in order so that you will know how much is in storage each month.

Notes

1. Sand, rice or some other material can be used instead of water.
2. Try starting the experiment with January, then start with October. In the U.S. and some other areas, hydrologists define a "water year" as starting in October, before the winter snow accumulation season. Do you get a different result?

Discuss Your Results:

1. Which months show a water shortage? Did this agree with your hypothesis? Are there any variables which you might now take into consideration in forming a hypothesis on water shortages at a site?
2. Are water shortages always in months with the least precipitation?
3. Are water shortages always in months with the highest temperatures?
4. During which months might you expect floods? Justify your hypothesis.

Testing Other Hypotheses With Your Model

Form hypotheses predicting how the water balance will change with changes in the variables

1. What happens if you have a particularly wet winter? (increase the winter precipitation)
2. What happens if you have an unusually dry summer? (decrease the summer precipitation)
3. What happens if you have an unusually hot summer (increase the water needed (PE) for the summer months)
4. What happens if you increase your storage through building an artificial reservoir? (increase Storage to 150 mm)

Test your hypotheses by changing the variables in the table and running the model again.

Adaptation for Older Students

Have students complete the Water Balance Table Work Sheet for their own or another site using GLOBE data.

1. Find the average monthly precipitation for each month and fill in the precipitation row in the table.
2. Find the average monthly temperature for each month and fill in the temperature row in the table.
3. Find the latitude for your site and fill in the latitude.
4. Find the PE for each month and fill in the PE row in the table. (PE may be calculated using the Calculating the PE Work Sheet in the appendix)
5. Find the difference between the precipitation and the water needed (PE) for the month.

- If there is more water than needed, enter the difference in the extra water row.
- Also enter this difference into the water storage row, adding it to any water that is already in Storage from the previous month. Note: In the first month you do not have a number to add from the previous month, so just enter the difference.
- Storage cannot be <0 or >100. Put the amount over 100 mm into runoff.
- If there is less water than needed, enter the difference into the extra water needed row.
- Subtract (water in storage from the previous month) - (extra water needed from the current month).
- Enter this number into the current month water storage box if it is >0.
- If the number is <0, enter 0 in the water storage box and your answer into the water shortage box.

6. Students should also calculate the actual amount of water loss through evapotranspiration:

   If Precipitation > PE:

   Actual Evapotranspiration = PE

   If precipitation < PE (as long as there is water in storage):

   Actual Evapotranspiration =

   Precipitation + extra water needed

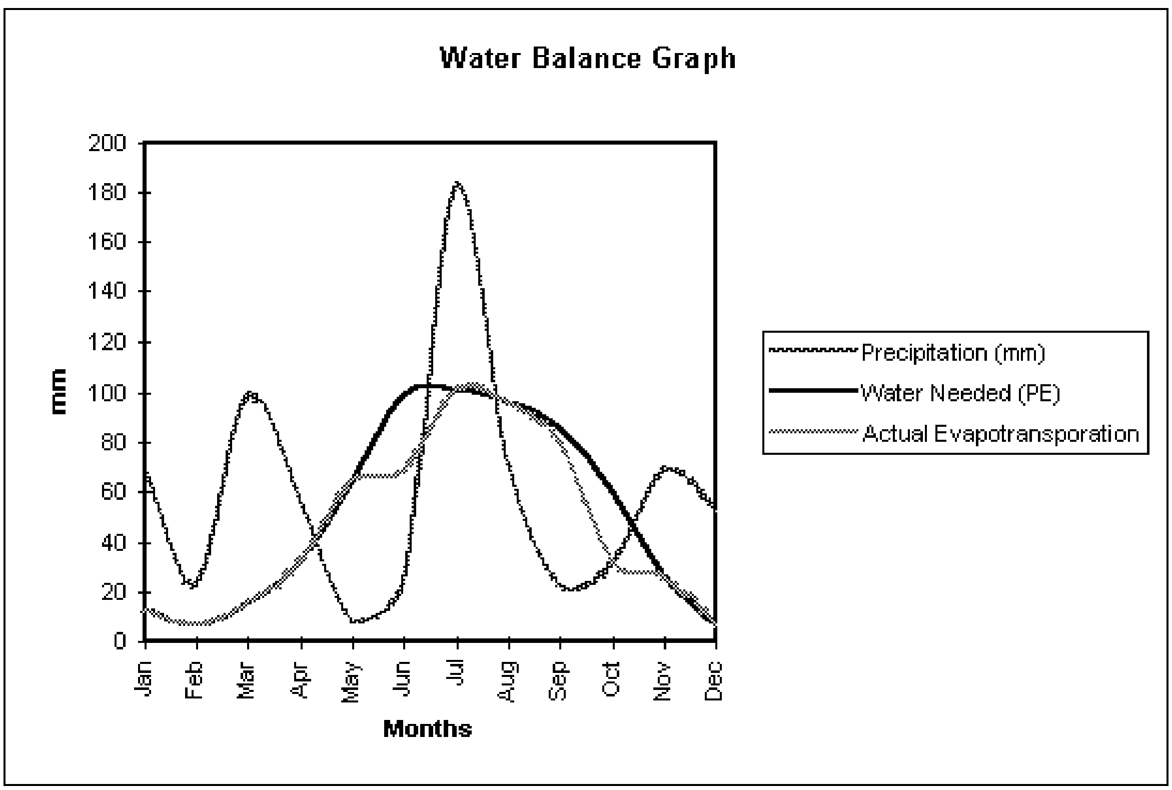
   You can only add the amount of water that is available in storage.

Graph the precipitation, actual evapotranspiration, and PE (3 lines) for the site on one graph using the months on the X axis, and mm of water on the Y axis for Precipitation, Actual Precipitation. See Figure HYD-L-18. Examine the graph and shade in areas where you have water surplus, water shortage, shortage use and recharge, and runoff.

Form hypotheses on how closely other variables may be correlated with the water balance. Use the GLOBE Data Server to investigate your hypotheses.

1. Examine the GLOBE soil moisture data from the site where you modeled water balance. What correlation can you find between your model and the soil moisture data?
2. Compare the GLOBE biomass data from the site where you model water balance. How closely do they compare? Do times of greatest biomass occur at the times of greatest water availability?
3. Graph your measurements of water chemistry. Are there any indications of changes in water balance which may affect the quality of a water body?

Figure HYD-L-18: Example Graph for Precipitation, Water Needed (PE), and Actual Evapotranspiration



Welcome Introduction Protocols Learning Activities Appendix

Modeling Your Water Balance

Hydrology Investigation

Water Balance Table Work Sheet

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Precipitation (mm)													
Water Needed (PE in mm)													
Extra Water													
Extra Water Needed													
Water in Storage													
Water Shortage													
Runoff													
Temperature (avg in Celsius)													

Example: Completed Water Balance Table (data from Mt. Lemmon, AZ, USA)

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Precipitation (mm)	69	23	98	56	9	23	183	71	23	32	68	54	
Water Needed (PE in mm)	13	7	16	33	64	99	101	96	86	60	27	7	
Extra Water	56	16	82	23			82				41	47	
Extra Water Needed					55	76		25	63	28			
Water in Storage	56	72	100	100	45	0	82	57	0	0	41	88	
Water Shortage						31			6	28			
Runoff			54	23									
Actual Evapotranspiration	13	7	16	33	64	68	101	96	80	32	27	7	
Temperature (avg in Celsius)	2	2	4	8	12	17	18	17	16	12	7	3	

Hydrology Investigation

Calculating Potential Evapotranspiration Work Sheet

This work sheet will allow you to calculate the Potential Evapotranspiration (PE) for any site using the temperature and latitude data from the GLOBE server. Potential Evapotranspiration may then be used in the Water Balance Activity.

Step 1

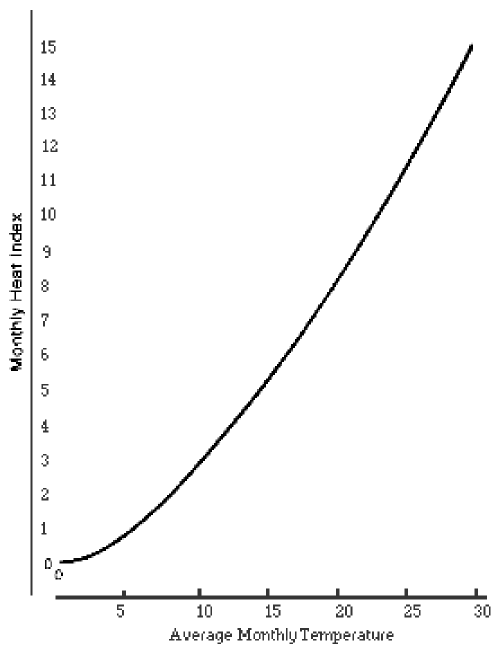
Find the Average Monthly Temperature for your site using the GLOBE data server.

Average Monthly Temperature:

Jan___Feb___Mar___Apr___May___Jun___Jul___Aug___Sep___Oct___Nov___Dec__

Step 2

Find the Heat Index for each month from the graph below.



Monthly Heat Index

Jan___Feb___Mar___Apr___May___Jun___Jul___Aug___Sep___Oct___Nov___Dec__

Step 3

Add the Monthly Heat Indexes together to get the Annual Heat Index.

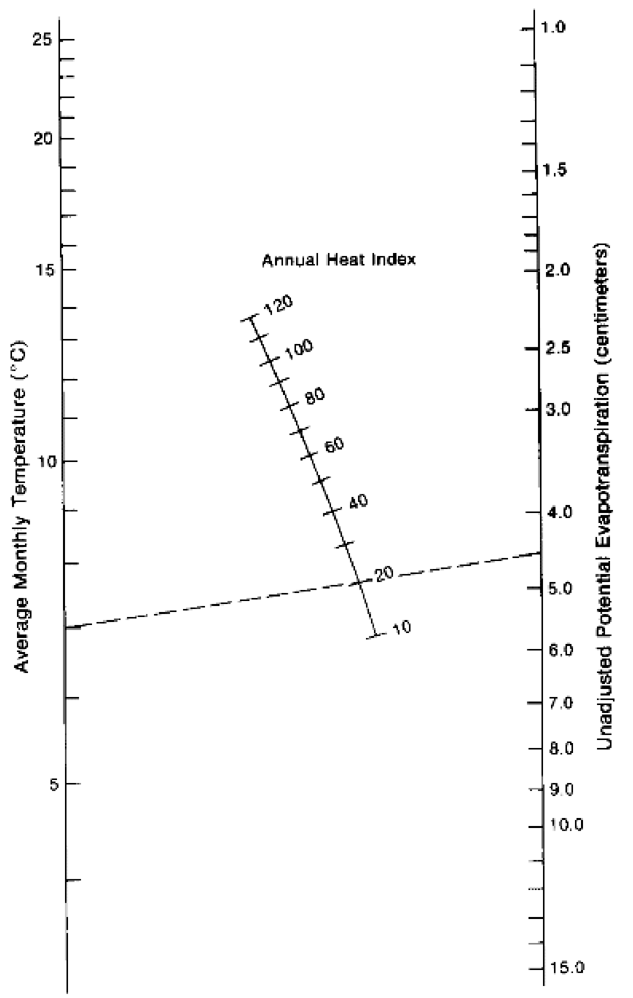
Annual Heat Index:__________

Step 4

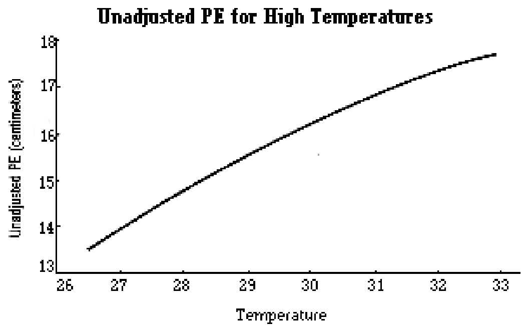
Using the Annual Heat Index and the Average Monthly Temperature for each month, find the Unadjusted Potential Evapotranspiration from the appropriate graph below.

NOTE: If the average temperature for the month is below 0, the Unadjusted Potential Evapotranspiration for that month is 0. If the average temperature for the month is greater than 26.5, use the Unadjusted Potential Evapotranspiration for High Temperatures graph below.

Unadjusted Potential Evapotranspiration



Note: To use the graph above, find your Average Monthly Temperature on the left and your Annual Heat Index in the center. Make a straight line joining the 2 points and continuing on until you cross the Unadjusted Potential Evapotranspiration line on the right. Read your Unadjusted PE from this line and record below. For higher temperatures, use the graph below to read your Unadjusted PE directly from the Temperature.



Unadjusted Potential Evapotranspiration for each month

Jan___Feb___Mar___Apr___May___Jun___Jul___Aug___Sep___Oct___Nov___Dec__

Step 5

Record the Correction Factor for each month from the table below.

Jan___Feb___Mar___Apr___May___Jun___Jul___Aug___Sep___Oct___Nov___Dec__

Step 6

Multiply the Correction Factor by the Unadjusted PE to find the Potential Evapotranspiration.

Potential Evapotranspiration

Jan___Feb___Mar___Apr___May___Jun___Jul___Aug___Sep___Oct___Nov___Dec__

Daylight Correction Factors for Potential Evapotranspiration

Latitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	1.04	0.94	1.04	1.01	1.04	1.01	1.04	1.04	1.01	1.04	1.01	1.04
10 N	1.00	0.91	1.03	1.03	1.08	1.06	1.08	1.07	1.02	1.02	0.98	0.99
20 N	0.95	0.90	1.03	1.05	1.13	1.11	1.14	1.11	1.02	1.00	0.93	0.94
30 N	0.90	0.87	1.03	1.08	1.18	1.17	1.20	1.14	1.03	0.98	0.89	0.88
40 N	0.84	0.83	1.03	1.11	1.24	1.25	1.27	1.18	1.04	0.96	0.83	0.81
50 N	0.74	0.78	1.02	1.15	1.33	1.36	1.37	1.25	1.06	0.92	0.76	0.70
10 S	1.08	0.97	1.05	0.99	1.01	0.96	1.00	1.01	1.00	1.06	1.05	1.10
20 S	1.14	1.00	1.05	0.97	0.96	0.91	0.95	0.99	1.00	1.08	1.09	1.15
30 S	1.20	1.03	1.06	0.95	0.92	0.85	0.90	0.96	1.00	1.12	1.14	1.21
40 S	1.27	1.06	1.07	0.93	0.86	0.78	0.84	0.92	1.00	1.15	1.20	1.29
50 S	1.37	1.12	1.08	0.89	0.77	0.67	0.74	0.88	0.99	1.19	1.29	1.41

Using the Table: For each month, look up the latitude of the site and the name of the month in the table above to find the Correction Factor for each month.

Note: The correction factors for latitude 50 N are used for all latitudes father to the north. The correction factors for latitude 50 S are used for all latitudes farther to the south.

Step 7

Record the PE in the appropriate row of your Water Balance Table.

*Adapted from Muller, Robert A and Oberlander, T. (1978) *Physical Geography Today: A Portrait of a Planet,* Random House.